K-FELDSPAR
IN UPPER MESOZOIC SANDSTONE UNITS
EAR ATASCADERO, SANTA LUCIA RANGE,
SAN LUIS OBISPO COUNTY, CALIFORNIA

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ABSTRACT

Detailed geologic mapping along the Nacimiento fault zone near Atascadero reveals a tectonically fragmented, incomplete (?) marine sedimentary sequence of Great Valley–type rocks of Late Jurassic to Late Cretaceous age. This is divided into two map units—the Toro Formation (Upper Jurassic–Lower Cretaceous) and the Atascadero Formation (Upper Cretaceous)—each of which can be subdivided locally. The Toro Formation appears to conformably overlie an ophiolite sequence of serpentinite and associated mafic intrusive and extrusive rocks of Late Jurassic (?) age. Franciscan mélange of probable Late Jurassic and/or Cretaceous age is in fault contact with all upper Mesozoic units and generally underlies them. Tertiary deformation—including low- and high-angle faulting—greatly complicates and obscures the earlier relations between the various Mesozoic units.

To help identify the various upper Mesozoic units where fossils are scarce or absent, 106 samples of sandstone were stained to determine the amount of K–feldspar present. Assuming that K–feldspar content increases systematically with decreasing age in the Great Valley sequence (Bailey and Irwin, 1959), several faulted Atascadero Formation sequences were discriminated from the older Toro Formation, and limited correlations were permitted between the faulted sequences. The few diagnostic fossil localities are consistent with that assumption. One of these fossil localities is highly significant in that it indicates a Cenomanian–Turonian age and is the only known "middle" Cretaceous (post–Valanginian to pre–Campanian) locality in the Santa Lucia Range.

The amount of K–feldspar distributed in sandstone of the composite Great Valley–type sequence, by age, is as follows: Late Jurassic–Early Cretaceous (Tithonian to Valanginian), little or none; early Late Cretaceous, 0.5–10%; late Late Cretaceous, generally 10–30%. The first definite appearance of K–feldspar was during the Cenomanian–Turonian, although the unfossiliferous Toro Formation (?) suggests a possible earlier appearance. The general lack of K–feldspar in Franciscan sandstone also suggests that the Franciscan mélange components are generally of pre–Late Cretaceous age.

The principal source of K–feldspar for Great Valley–type rocks is considered to be the granitic rocks of the Salinian block to the east, centering in the southern La Panza Range. Radiometric ages determined for the granitic rocks—and their probable time of emplacement and subsequent unroofing—are compatible with the age–distribution of K–feldspar in the Great Valley–type rocks.

Special Report 128

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by

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K–Feldspar in Upper Mesozoic Sandstone Units Near Atascadero, Santa Lucia Range, San Luis Obispo County, California

By EARL W. HART

INTRODUCTION

The primary purpose of this paper is to present data on the K–feldspar content of upper Mesozoic sandstone units near Atascadero and to examine the systematic variations and use of that data as a crude indicator of stratigraphic position (i.e., relative time) and correlation. Secondary purposes are (1) to document the existence of mid–Cretaceous Great Valley–type beds in Paradise Valley and (2) to provide preliminary descriptive data on the upper Mesozoic stratigraphic and tectonic units that may be of use to other workers in the Santa Lucia Range.

This study is based on comprehensive mapping (scale 1:24,000) in the vicinity of Atascadero, San Luis Obispo County, (figure 1) and is part of a broader investigation of the Nacimiento and Rinconada fault zones conducted for the California Division of Mines and Geology during 1965–1971 (Hart, 1976). Mapping near Atascadero was conducted mainly from 1968 to 1970. This report is a partial condensation and revision of a thesis submitted in partial fulfillment of the requirements for a degree of Master of Arts (Hart, 1971).

Previous Work

The K–feldspar content of sandstone from upper Mesozoic rock units in the northern Coast Ranges (west Sacramento Valley) of California was first studied regionally by Bailey and Irwin (1959). They showed that average K–feldspar content of the Upper Jurassic and Lower and Upper Cretaceous parts of the Great Valley sequence of west–side Sacramento Valley systematically increases with decreasing age. This systematic increase was attributed to progressive unroofing of the Klamath Mountains and Sierra Nevada batholiths and/or increasing richness of K–feldspar in the younger plutonic rocks. The K–feldspar content of the deformed and partly metamorphosed Franciscan sandstone was viewed somewhat more skeptically, although scarce fossil data suggested that a corresponding relationship may hold true for the Franciscan.

Ojakangas (1968) verified these conclusions after studying the petrology of a complete and intact 31,900–foot thick section of Great Valley sequence in the Cache Creek–Rumsey Hills area of west Sacramento Valley. That conformable sequence of fifteen local map units not only showed a general increase upward in K–feldspar content of sandstone, but revealed abrupt major increases during Berriasian (earliest Cretaceous), Albian (latest Early Cretaceous) and Campanian (late Late Cretaceous) times (figure 4).

Comparable systematic increases in K–feldspar content in sandstone with decreasing age were also observed by Colburn (1961), who mapped and sampled a nearly complete, but partly faulted, sequence of Great Valley rocks at Mount Diablo. Bailey and others (1964) expanded their earlier work and sampled upper Mesozoic sandstone of the Santa Lucia Range. Although they clearly imply that the K–feldspar content increases with decreasing age in this region, this is not supported by their sample data (their plate 2).

The distribution of K–feldspar in upper Mesozoic sandstone of the southern Santa Lucia Range has also been studied by Hsü (1969) and Gilbert and Dickinson (1970). Neither, however, demonstrates a clear relation between K–feldspar and stratigraphic position because of inadequate sampling of the structurally complicated, fossil–poor sequences.

The inferred structural and stratigraphic relations of some of the upper Mesozoic units of the Atascadero area and adjacent area to the south and west are discussed in detail by Page (1972). Additional aspects of the geology of the Atascadero vicinity that are pertinent to this report have been described by Fairbanks (1904), Taliaferro (1943, 1944), McClure (1969), and Bailey and others (1970).

In the Santa Lucia Range, it has heretofore been difficult to evaluate the hypothesis that the K–feldspar content of upper Mesozoic sandstone increases with decreasing age, because (1) the Great Valley–type sequences are tectonically fragmented and internally deformed; (2) no complete and intact sequence is known; and (3) upper Mesozoic fossils are scarce. It is emphasized that the allochthonous nature of the upper Mesozoic rocks has been recognized only in the last few years; and, in this writer's opinion, these units probably are more disturbed than many present workers acknowledge. This paper, then, is an effort to relate K–feldspar content to stratigraphic position (i.e.,relative time) and to indicate its usefulness and limitations as a tool of correlation.

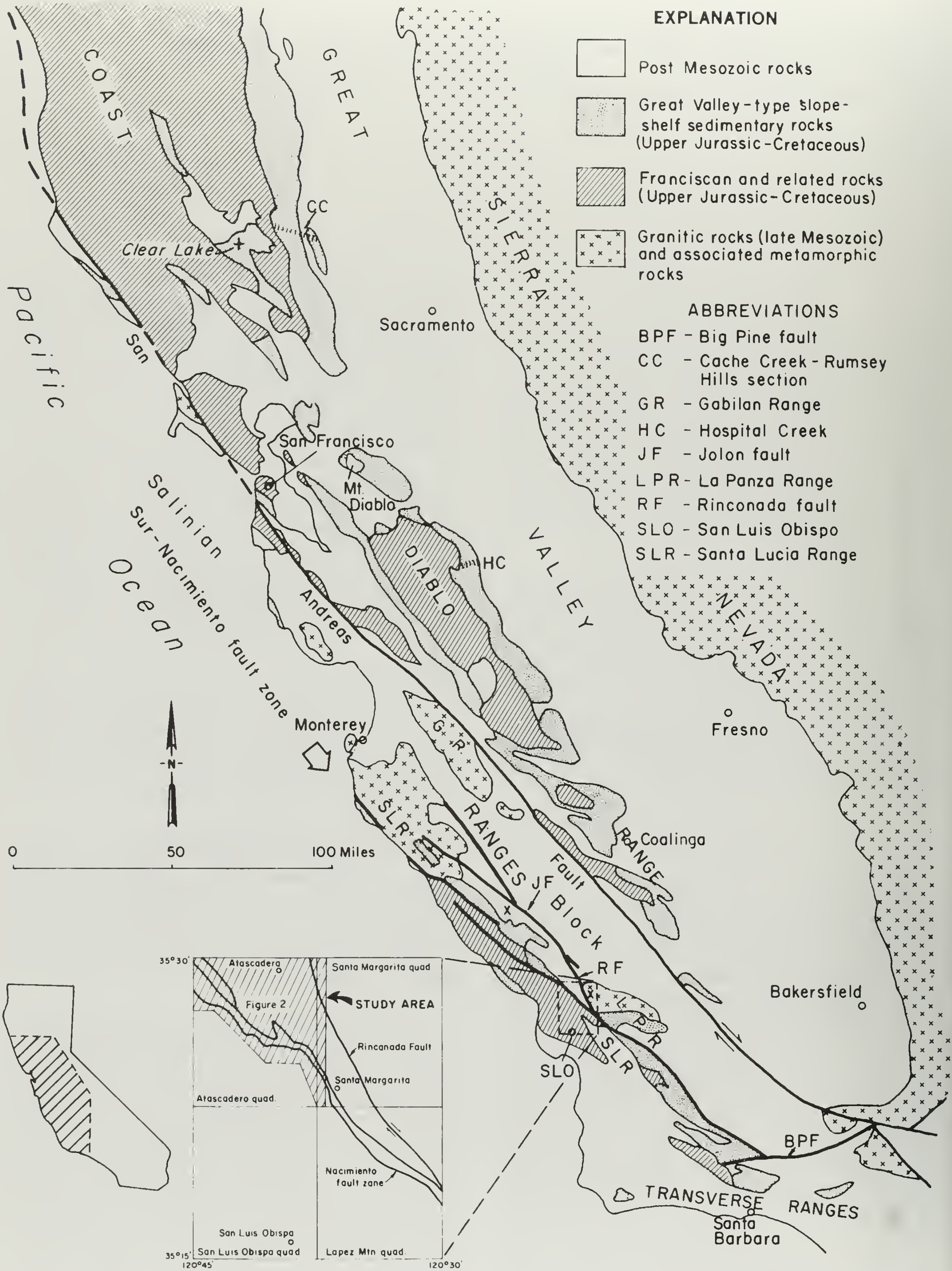

Figure 1. Location map showing study area, main geologic provinces, and outcrop distribution of Great Valley–type, Franciscan, and granitic rocks (modified from U.S. Geological Survey, 1966). X–X' shows location of apparently offset upper Oligocene–lower Miocene beds.

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LITHOLOGIC UNITS NEAR ATASCADERO

The study area lies astride the so-called Nacimiento fault zone, which, as it is ordinarily mapped, is a complex of late Mesozoic and Cenozoic faults of different tectonic styles. To the northwest, in the northern Santa Lucia Range, the Sur-Nacimiento fault zone is considered to mark the late Mesozoic boundary between the continental plate (Salinian block) on the northeast and the underthrust former oceanic plate on the southwest (Page, 1970). The Mesozoic rocks lying west of the fault consist of oceanic and continental margin deposits now accreted to the continent. The Salinian block, adjacent oceanic rocks to the west, and intervening Sur-Nacimiento fault zone are considered to be a southern extension of the Sierra Nevada and its concealed western margin which have been dislocated northwestward (right-laterally) several hundred miles along the San Andreas fault during Cenozoic time (Hill and Dibblee, 1953; McKenzie and Morgan, 1969; Page, 1970, p. 667, 669). On a smaller scale and more locally, the western margin of the Salinian block also appears to have been offset right-laterally along the Rinconada fault just east and north of the map area (figure 1).

The upper Mesozoic map units of the study area (figure 2)* are similar in stratigraphic position, rock type, and style of tectonic deformation to other upper Mesozoic rocks of the Santa Lucia Range west of the Salinian block. Several map units are recognized and may be classed as stratified or tectonic for the purposes of mapping. The stratified units are (1) the ophiolite sequence of ultramafic rocks (mainly serpentinite and mafic intrusive rocks) and overlying mafic volcanic rocks and (2) the Great Valley-like sequence of clastic marine sedimentary rocks of the continental margin. The Franciscan mélange, a tectonic unit, is a chaotic mixture of sedimentary, volcanic, and other rocks. The stratigraphic units are moderately to extensively deformed and disrupted and, in places, appear to grade tectonically into the Franciscan mélange.

Interpreted in terms of global tectonics (e.g., Isacks and others, 1968; Morgan, 1968; Le Pichon, 1968), the rock units presumably represent remnants of the oceanic crust and upper mantle(?) (ophiolite sequence), continental margin sediments (Great Valley-type sequence), and subduction zone deposits resulting from mixing of oceanic and trench deposits (Franciscan mélange). These units probably were brought together under the dynamic conditions of converging crustal plates. More specific upper Mesozoic processes and morphologic conditions (i.e., relative positions of trenches, ridges, and magmatic arcs) are considered by Hamilton (1969), Bailey and others (1970), Dickinson (1970), and Page (1972).

The complexity of the Santa Lucia Range is not solely due to Mesozoic tectonism but has been complicated by low- and high-angle Cenozoic faulting and folding. Only where Cenozoic strata are present can later structural features be differentiated from tectonic effects of the late Mesozoic. In the absence of Cenozoic strata, interpretation of late Mesozoic events is highly inferential. This is particularly so where Great Valley-type strata and ophiolite rocks are enclosed in Franciscan mélange. Are these inclusions part of the Franciscan subduction zone deposits, or were they emplaced structurally after the mélange was formed? For field purposes, relatively coherent large blocks (as small as 1000 feet long) were arbitrarily assigned to the ophiolite and Great Valley-type sequences. Similar but smaller blocks were more difficult to distinguish on a map as being separate from the Franciscan and are included in the mélange.

The distribution of Cenozoic rocks is shown on figure 2. These include unnamed Oligocene(?) nonmarine sedimentary beds, Miocene marine sedimentary and volcanic rocks (Monterey and Santa Margarita Formations), Pliocene-Pleistocene nonmarine sedimentary rocks (Paso Robles Formation), and late Quaternary alluvial deposits (partly omitted from the map).

Franciscan Mélange

This unit is a chaotic mixture of sandstone with some interbedded shale, altered volcanic rocks (greenstone), and thin-bedded chert with minor amounts of serpentinite, diabase-gabbro, conglomerate, blueschist facies metamorphic rocks, and jasper. These rocks exist as fault blocks and slices of all sizes, perhaps as much as half a mile long, which are set in a highly sheared matrix of the same rock types and an undetermined amount of sheared shale. Some of these blocks resemble rocks of the stratified upper Mesozoic units mapped; others are dissimilar. This unit is similar in lithology and tectonic style to the chaotic-type Franciscan observed elsewhere in California (Blake, 1970).

Franciscan sandstone is typically massive graywacke with little or no bedding apparent. It is medium to coarse grained, hard, partly calcareous, and commonly cut by irregular veinlets of calcite and quartz. The sandstone contains abundant quartz grains, altered volcanic debris, chert and plagioclase with lesser

*(see center-spread map)

amounts of clastic sedimentary and metamorphic grains, biotite, and various minor constituents. K–feldspar is usually absent, although widely scattered grains (possibly altered volcanic glass in some cases) are present locally. Dark–gray, hard shale and siltstone are locally associated with the sandstone as thin interbeds. Thick sequences of shale or mudstone are rarely exposed but may constitute much of the sheared matrix of this unit.

Some Franciscan sandstone is atypical, being somewhat softer, brownish (weathered?), and locally constituting deformed stratified sequences with mudstone.

The Franciscan appears to contain inclusions of the other less–deformed upper Mesozoic units (e.g., Toro Formation, ophiolite) and, in a sense, may locally grade tectonically into some of these units. The larger coherent blocks and fault slices of serpentinite, mafic volcanic rocks and Toro Formation that lie within the Franciscan mélange have been "mapped–out" of the mélange where feasible. The Franciscan underlies most of the other Mesozoic sequences in the mapped area but locally has been thrust over the Upper Cretaceous and Tertiary rocks.

Ophiolite Sequence

Ultramafic and mafic igneous rocks, exposed in the southwest part of the study area, are subdivided into two mappable units: (1) serpentinite and associated intrusive rocks and (2) overlying mafic volcanic rocks and locally associated chert. Such rock associations are believed to be remnants of a former oceanic crust and are commonly termed ophiolite. Locally, they have been interpreted as Mesozoic oceanic crust (Page, 1972; Bailey and others, 1970). The ultramafic–mafic sequence is apparently overlain conformably by marine strata of the Toro Formation (Upper Jurassic–Lower Cretaceous). Together, the ophiolite–Toro succession occupies a northeast portion of a long, northwest–trending, complexly faulted, synclinal thrust plate that rests on Franciscan mélange (Page, 1972).

Massive to sheared serpentinite, derived from pyroxene–bearing peridotite and dunite, is common along the margins of, and mainly underlies, the mafic volcanic units. Hard unweathered diabase and subsidiary amounts of gabbro, pyroxenite, and leucocratic quartz diorite(?) commonly intrude the serpentinite as dikes, sills, and possible larger intrusive masses. The dikes may have been feeders to the commonly associated and overlying mafic volcanic rocks (Page, 1972).

Mafic volcanic rocks are somewhat varied in composition and textures and include such rock types as diabase, fine–grained rocks (lava?), porphyritic rocks, tuff breccia, and pillow basalt. Most have been altered to greenstone, but the primary features, such as vesicles and pillows, can often be recognized where shearing is not pervasive. The diabase associated with the volcanic rocks appears to be more altered and weathered than the diabasic dike–rocks associated with serpentinite. Bedded chert is locally associated with the volcanic rocks, mainly overlying them.

In places, the volcanic unit is crudely stratified parallel to the contact of the underlying serpentinite (e.g., Frog Pond Mountain) and may be essentially depositional on it. In most places, however, the contact relations of the mafic volcanic rock masses are faulted or obscure.

Great Valley–type Sequence

The Great Valley–type strata of the study area (and probably much of the rest of the Santa Lucia Range) are mainly composed of fine to coarse terrigenous clastic sediments, which include abundant turbidites and shallow water(?) deposits, as well as some hemipelagic sediment. These marine deposits apparently formed along a continental margin—mainly on the slope.

The term "Great Valley sequence" was applied by Bailey and others (1964, p. 123) to the sequence of "continental shelf and slope" sediments that is "thickest and best exposed in the western part of the Great Valley, though it is not limited to the Great Valley."

The Great Valley–type strata of the Santa Lucia Range, however, cannot be considered unequivocally to have been coextensive with the Great Valley sequence east of the Salinian block, although both are generally similar in lithology and age. Furthermore, the Great Valley–like rocks of the Santa Lucia Range appear to have important stratigraphic gaps—particularly in the "middle" Cretaceous part of the sequence. There is no complete intact sequence in this area as there is in western Sacramento Valley. The sequences of the Santa Lucia Range also appear to be relatively thin. However, it does seem likely that the Great Valley sequence east of the Salinian block and the Great Valley–type rocks west of that block were deposited along a common continental margin. Hsü (1971), however, has suggested a model that conflicts with this interpretation.

The Great Valley–type rocks of the map area are subdivided into an Upper Jurassic–Lower Cretaceous unit and an Upper Cretaceous unit. These units correspond rather closely to the Toro and Atascadero Formations, respectively, of Fairbanks (1904), although he did not recognize them to be allochthonous or internally complicated. In spite of Fairbanks' definitions, the Toro Formation (as used herein) has no identifiable top and the Atascadero Formation has no recognizable base or top. Other formal and informal designations also have been used for equivalent strata in and near the map area (e.g., Taliaferro, 1943, 1944; Hall and Corbató, 1967; Hsü, 1969; Gilbert and Dickinson, 1970).

The Toro Formation is correlative in age and lithology with the lower or "Knoxville" part of the Great Valley sequence of western Sacramento Valley. The Atascadero Formation is largely similar in age and lithology to the upper Great Valley sequence, although the upper and lower limits of neither unit is precisely defined. Strata equivalent to the "middle" Great Valley sequence appear to be largely missing from the Santa Lucia Range, although fossiliferous beds of intermediate character and age (Cenomanian or Turonian) were identified at one locality in the study area (Paradise Valley). Nowhere else in the Santa Lucia Range are beds of post-Valanginian to pre-Campanian age definitely known (D.L. Jones, 1970, personal communication).

Toro Formation

This Upper Jurassic to Lower Cretaceous unit was named and described by Fairbanks (1904) for dark shale and thin-bedded sandstone exposed in Toro Creek about 2 miles west of the study area. Its general structure—a northwest-trending syncline—and its distribution are shown by Fairbanks. Only part of the northeast flank of this unit is exposed in the study area, where it is highly faulted and deformed (figure 2). With one possible exception, the unit is everywhere in fault contact with other Mesozoic units in the map area.

Typically, the Toro Formation consists of abundant dark-gray to olive-gray, brittle shale and mudstone with common thin interbeds of fine graywacke and siltstone. Massive thick beds of medium- to coarse-grained, lithic graywacke and pebble conglomerate are sporadically distributed through the shale and these also characterize the unit. The sandstone is lithic wacke composed of abundant volcanic debris (partly mafic), sedimentary rocks (chert plus shale, siltstone, sandstone), and quartz in subangular grains. Plagioclase, metamorphic rock grains, and mica are common. K-feldspar is virtually absent. Turbidity current features (graded beds, cross-lamination, rhythmic interbedding with shale) suggest basinal deposition. The conglomerate contains abundant rounded, dark-gray chert pebbles; granitic clasts are absent. Several species of *Buchia* are associated with the coarser grained rocks (table 1). Southeast of Eagle Peak, near the serpentinite-diabase unit, the shale is hard and presumably siliceous. Similar shale with Radiolaria (B.M. Page, 1970, personal communication) is mapped as a "bedded chert" unit at the base of the Toro by Page (1972). Silicified shale with black chert(?) also is exposed near the base of the Toro Formation just west of Eagle Peak in Atascadero Creek.

"Atypical" gray to greenish gray, fine- to medium-grained, laminated to well-bedded graywacke (turbidite) with mudstone interbeds is exposed 1 mile southeast of Eagle Peak in a highly deformed sequence (JKt? on figure 2). These beds contain 1-5% K-feldspar—mostly orthoclase with minor perthite and microcline. The atypical sandstone also contains more plagioclase, volcanic material, and epidote and less chert and other sedimentary debris than the more typical Toro. Both types of sandstone are partly chloritized and otherwise altered, as well as densely packed.

Composition of the sandstone and conglomerate suggests principal volcanic and sedimentary sources and a subsidiary schistose metamorphic source for the typical Toro Formation. Compared to the typical Toro, the atypical beds show an increase in metavolcanic material (epidote), a decrease in sedimentary and schistose metamorphic rocks, and the introduction of an acid plutonic source.

The Toro Formation is moderately to highly deformed internally with numerous small faults and pervasive shears subparallel to the bedding. Attitudes vary greatly over short distances, but local sequences as much as a few hundred feet thick can be recognized as being more or less intact and coherent. Massive conglomerate-sandstone beds seldom can be traced more than a quarter of a mile.

The base of the Toro presumably is partly removed by faulting. This is indicated by the discordance of dips and by the presence of Valanginian fossils (and absence of older fossils) near the ophiolite unit contacts (figure 2, table 1). The only apparent depositional contact noted is along upper Atascadero Creek, just west of Eagle Peak, where a somewhat atypical shale-sandstone sequence with siliceous (black chert?) basal beds appears to conformably overlie altered vesicular pillow(?) lava. The top of the Toro is not recognizable because of deformation; the overlying Atascadero Formation is in fault contact.

The age of the Toro, based on fossils in and adjacent to the map area, is Tithonian (Late Jurassic) to Valanginian (Early Cretaceous) (table 1). However, two Upper Cretaceous palynomorph (Angiosperm pollen) localities, approximately 3 to 5 miles west of the map area, are reported in the Toro Formation (mapped as "lower Great Valley unit") by Gilbert and Dickinson (1970, p. 950-952). Also, atypical K-feldspar-bearing beds identified southeast of Eagle Peak may be younger than typical Toro beds, which contain no more than a trace of K-feldspar. The lithologic and petrologic similarity to the Atascadero Formation unit 1 in Paradise Valley (see below) suggests a possible "middle" Cretaceous age for the atypical Toro. The relationship of the atypical K-feldspar bearing sequence to the typical Upper Jurassic-Lower Cretaceous Toro is uncertain. These beds may be depositional on the Toro, or they may have been emplaced by gravitational sliding and slumping penecontemporaneous with deposition or by later faulting. Whether the atypical beds should be assigned to the Toro Formation is perhaps arbitrary. Because of the uncertain relationship between typical and atypical Toro, it is probably best to view these beds collectively

Table 1. Upper Mesozoic fossil localities near Atascadero (see figures 2 and 3).

Map locality	Key fossils	Age
A[1]	*Linearia multicostata* (Gabb) and *Glycymeris* sp.	Late Cretaceous (probably Cenomanian or Turonian)
B[2]	Angiosperm pollen (2 types) Dinoflagellate (1 type)	Late Cretaceous (?)
C[1]	*Buchia piochii* or *B. uncitoides* (specimens crushed)	Late Jurassic (Tithonian) or Early Cretaceous (Berriasian)
D[1]	*Buchia pacifica* and *B. keyserlingi*	Early Cretaceous (Valanginian)
E[1,3]	*Buchia keyserlingi*	Early Cretaceous (Valanginian)
F[1]	*Buchia pacifica*	Early Cretaceous (Valanginian)
G[1]	*Glycymeris veatchii* (Gabb) var. *anae* (Smith)	Late Cretaceous (Campanian or younger)
H[1,3]	*Pterotrigonia evansana*	Late Cretaceous (Campanian)
I[1]	*Baculites* sp. (scraps)	Late Cretaceous

[1] Identified by D.L. Jones, U.S. Geological Survey, Menlo Park, Calif.
[2] Identified by W.R. Evitt, Stanford University, Palo Alto, Calif.
[3] *In* Gilbert and Dickinson, 1970, p. 952.

NOTE: Fossil specimens identified for this study are held in the collections of the identifying paleontologists. See Appendix for additional descriptions of localities A, B, and G.

as part of a larger deformed Great Valley–type sequence with local stratigraphic gaps. Such gaps commonly develop as part of the normal erosional–depositional–slumping processes active on continental margins.

Atascadero Formation

This unit is essentially the same as the Atascadero Formation of Fairbanks (1904), with the exception of beds (units 1 and 2) in the Paradise Valley area that were assigned to the Toro Formation by Fairbanks. He named the unit for exposures in Atascadero Creek. As used in this report, the Atascadero designates those loosely correlated, sparsely fossiliferous, deformed and disrupted sequences of Upper Cretaceous strata from four principal fault blocks (numbered I to IV, figure 2).

Much of the Atascadero consists of undifferentiated sequences characterized by thick, massive beds of coarse arkosic sandstone. Associated are well-bedded sequences of sandstone, siltstone, and soft mudstone. In contrast to, and less characteristic of, the Atascadero are dark-gray mudstone–sandstone sequences intermediate in character between the Toro and typical Atascadero Formation rocks. These occur in lower parts of three of the fault block sequences. In two of these (fault blocks III and IV), the lower sequences are poorly defined and unfossiliferous. In fault block I, a portion of the Atascadero can be subdivided into four transitional units that show a progressive upward change from lower dark fossiliferous mudstone–shale (unit 1) to typical massive feldspathic sandstone (unit 4) characteristic of the undifferentiated Atascadero.

The undifferentiated and upper parts of the Atascadero Formation, including units 3 and 4 of the Paradise Valley area, are characterized by thick beds of massive coarse sandstone that generally weather to bold outcrops. Interbedded are well-bedded sequences of fine to coarse sandstone, siltstone, and mudstone that show common turbidity current features. Associated are local lenses of conglomerate and conglomeratic sandstone. Much of the sandstone is medium to coarse, arkosic, and characterized by abundant flakes of crinkly biotite. The mudstone is medium gray and soft. The undifferentiated and upper Atascadero beds are rather typical of uppermost Cretaceous rocks elsewhere in the Coast Ranges. Diagnostic fossils in the "upper" beds of fault block IV substantiate its Late Cretaceous (Campanian–Maestrichtian) age locally (table 1 and figure 2).

The main granular constituents of the typical upper and undifferentiated Atascadero sandstones are quartz (30–40%), feldspars (30–50%), and lithic grains (10–30%). These are generally subangular, moderately sorted, densely packed, and deformed.Monocrystalline quartz predominates over coarsely sutured to polycrystalline quartz, but both are common. Plagioclase (commonly oligoclase) constitutes one–third to two–thirds of the feldspars. K–feldspar makes up 10–30% of the grains, of which orthoclase greatly predominates over microcline and the less abundant sanidine. The feldspars are commonly perthitic and less commonly myrmekitic. Partial alteration to, or replacement by, sericite, kaolin, calcite, albite, and sometimes laumontite is widespread, making quantitative determinations of the feldspars rather difficult. A variety of rock types comprise the lithic fraction, but volcanic and hypabyssal rocks (chiefly silicic) are most common. Chert, clastic sedimentary rocks, and foliated metamorphic grains (micaceous aggregates) are also present. Large flakes of crinkly, partly chloritized biotite, similar to that found in the granitic rocks of the La Panza Range, are characteristic and make up 2–10% of the grains. Detrital epidote, chlorite, calcite, and carbonaceous debris are usually present and locally common. Phyllosilicates constitute most of the matrix—usually 10–15% of the rock. Secondary chlorite partly replaces the matrix in some rocks, and interstitial laumontite has been observed. Calcite commonly is present, both as a cement and replacement material, and comprises 20–50% of some sandstones.

The over–all composition and the relative abundance and textures of quartz, feldspars, and biotite suggest that acid plutonic rocks were the chief source

of sand. Volcanic rocks and, probably to a lesser extent, sedimentary and metamorphic rocks were associated with the plutonic source terrain. A significant reworking of older sedimentary rocks can be ruled out by the compositional and textural immaturity of the typical Upper Cretaceous sandstones. Paleocurrent directions for the Upper Cretaceous beds are reported to be toward the west and southwest in the Atascadero fault block (McClure, 1969), indicating a general easterly source, where plutonic rocks of appropriate age and composition are exposed in the La Panza Range (figure 1).

Conglomerate clasts of the upper Atascadero Formation indicate a provenance of similar composition but with different proportions of rock types. Pebbles and small cobbles consist mainly of volcanic rocks (commonly porphyries) with subordinate amounts of granitic and aplitic rocks, quartzite, and milky quartz. Clast counts at three localities along State Route 41 in the mapped area were made by McClure (1969, table 3). These show the following constituents (with average percentages): silicic volcanic (35%), basic volcanic (28%), quartzite (14%), plutonic igneous (mainly quartz monzonite) (12%), vein quartz (4%), other metamorphic (4%), volcaniclastic (1%), and sedimentary (1%). The silicic volcanic rocks are dacite to rhyolite with phenocrysts of K-feldspar, plagioclase, and quartz; basic volcanic rocks include basalt and andesite.

Lower sequences of the Atascadero Formation can be mapped with varying degrees of confidence and completeness in three of the four fault blocks. These contain abundant dark mudstone and shale in contrast to the more typical Atascadero rocks described above. The lower sequences are undifferentiated in fault blocks III and IV, where they are identified as Kal on figure 2. In fault block I, the lower beds of Paradise Valley are less deformed and are designated units 1 and 2 of a transitional sequence (see "Paradise Valley sequence"). These lower Atascadero sequences generally consist of hard to firm, dark-gray to olive-gray mudstone and shale with thin to thick rhythmic interbeds of sandstone and siltstone (turbidite) and minor interbeds and concretions of impure limestone. The lower beds are intermediate in character between typical Toro and typical Atascadero rocks. The sandstone contains abundant lithic debris and generally 0.5-10% K-feldspar. The lower beds also show considerable internal deformation. Although the lower dark mudstone-sandstone sequences of the Atascadero are generally similar to each other throughout the map area, specific stratigraphic relations are unknown.

The "Paradise Valley sequence" is described in some detail here because it is a relatively intact stratigraphic sequence that is transitional in character and intermediate in age, lithology, and K-feldspar content between typical Toro Formation and Atascadero Formation rocks. It is of significance both in the map area and in the Santa Lucia Range where strata of post-Valanginian to pre-Campanian age were previously not definitely known. The northeast-dipping sequence, although locally deformed, can be divided into four conformable stratigraphic units (units 1 to 4 from base upwards) (figure 3). The homoclinal sequence is more than 5,000 feet thick, although its base is truncated by a fault to the southwest. To the southeast (along strike) and east (upward), the unit appears to disintegrate into more highly disturbed beds typical of the undifferentiated Atascadero.

Unit 1 of the sequence consists mostly of dense, dark-gray to olive-green shale, mudstone and lithic sandstone with some siltstone, and impure limestone. The unit is at least 2,000 feet thick in outcrop and can be subdivided into three gradational subunits on the basis of sandstone content. The unit appears to be truncated on the southeast by a minor thrust fault. To the northeast, it is conformably overlain by, and gradational with, unit 2. The sandstone of unit 1 is a graywacke composed of abundant quartz, plagioclase, and lithic debris with subordinate K-feldspar, biotite, chlorite, and epidote. Euhedral plagioclase is commonly associated with chlorite and epidote. Anhedral plagioclase is also common. K-feldspar constitutes 0.5 to 10% of the sandstone. Much of it appears to be orthoclase, but microcline and perthite are present and a few grains of sanidine and some myrmekite were identified. Some coarsely sutured quartz also is present. Of the lithic grains, mafic volcanic and hypabyssal rocks appear to be most abundant, but silicic volcanics are present. Chert and clastic sedimentary rock grains are present in nearly all samples and are common in some. Detrital calcite grains and fossil debris are present locally. The matrix consists of abundant phyllosilicates, including squashed grains of biotite and soft rocks. Chloritization, calcification, and other types of alteration have extensively modified the original grains and matrix.

Unit 2 is a well-bedded sequence of graywacke with subordinate mudstone, siltstone, and impure limestone. It is nearly 1000 feet thick. The lower part contains 1- to 3-foot thick beds of resistant massive sandstone that alternate with thinner-bedded sequences of finer grained sandstone, shale-mudstone, siltstone, and some impure limestone. The upper part of the unit is typified by hard, thin-bedded, platy (flaggy), calcareous, biotitic graywacke and shale-mudstone in roughly equal amounts. The sandstone of unit 2 contains 6 to 15% K-feldspar—chiefly orthoclase with minor microcline and myrmekite. Compared to unit 1, unit 2 sandstone contains more acid plutonic debris (K-feldspars, monocrystalline to coarsely sutured quartz, large flakes of biotite) and less mafic volcanic-hypabyssal debris (euhedral plagioclase, chlorite, epidote). The higher unit also contains more metamorphic debris (quartzite, schist, muscovite).

Unit 2 of the Atascadero fault block is overlain by unit 3—a sandier, locally conglomeratic, softer, more

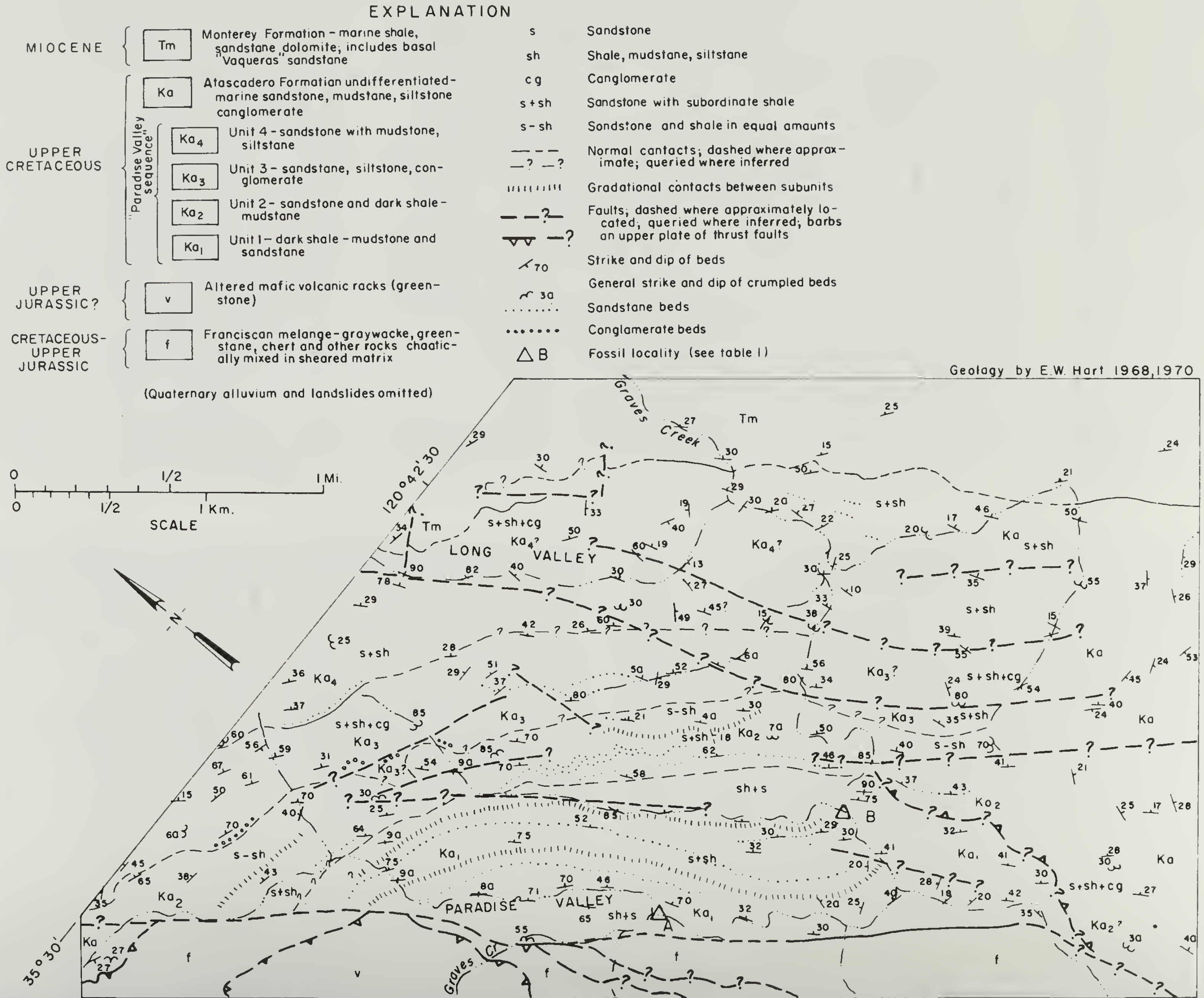


Figure 3. Geologic map of Paradise Valley area west of Atascadero, California. See figure 2 for location.

massive, poorly bedded sequence about 1,200 feet thick. The contact between units 2 and 3 is locally faulted and somewhat obscure. A conglomerate locally present at the base of unit 3 suggests a local unconformity, but this cannot be evaluated without fossil evidence. Sandstone of unit 3 contains abundant quartz, plagioclase, K-feldspar (8–15%), and volcanic debris plus subordinate biotite, sedimentary rocks (mainly chert), and metamorphic rocks (quartzite, schist, argillite). Petrologically, it is most similar to sandstone of unit 2.

Unit 3 is overlain conformably by unit 4, which consists of thick massive sandstone beds and interbedded turbidite sequences aggregating more than 1,000 feet in thickness. It is typical of the more characteristic feldspathic sandstone of the undifferentiated and upper parts of the Atascadero Formation. Unit 4 is overlain and gives way to the southeast to similar strata that are more highly faulted and folded and that have an uncertain stratigraphic relation to the Paradise Valley sequence.

The age of the "Paradise Valley sequence" is not fully known. The only diagnostic fossils, found near the faulted base of unit 1, are mollusks of earlyLate Cretaceous age—probably Cenomanian or Turonian (D.L. Jones, 1970, personal communication; also see Locality A, Appendix). Palynomorphs of probable Late Cretaceous age were identified (W.R. Evitt, 1968, personal communication) somewhat higher in the unit (Locality B, Appendix). Unidentified Radiolaria and *Inoceramus* prisms also were found in mudstone near the top of unit 1 (C.C. Church, 1970, personal communication).

Lithologically, the "Paradise Valley sequence" is transitional in two respects. Units 2 and 3 are transitional, being intermediate in character and position between lower Atascadero unit 1 and "upper" Atascadero unit 4 which, although of unknown stratigraphic position within the Atascadero as a whole, is typical of the Atascadero in the map area. Further, unit 1 of the sequence is transitional both in character and age between typical Toro and Atascadero rocks elsewhere in the map area.

Lower and "upper" undifferentiated units of fault block III are crudely analogous to the "Paradise Valley sequence". The lower dark mudstone-shale and thin interbeds of dense sandstone closely resemble both unit 1 and the Toro Formation. Petrologically, however, the sandstone of the lower part of fault block III is more like that of unit 1. The overlying strata contain massive, feldspathic, biotitic sandstone similar to other "upper" Atascadero beds. Sandstone samples from the lower and upper units show 3 to 10% and 10 to 15% K-feldspar, respectively (figure 2). In both units, the principal K-feldspar appears to be orthoclase with minor microcline and myrmekite. No sanidine was noted. Plagioclase, abundant in both units, is partly euhedral in the lower unit. It would appear that the upward increase in K-feldspar corresponds to an increase in acid plutonic debris and a decrease in mafic volcanic debris.

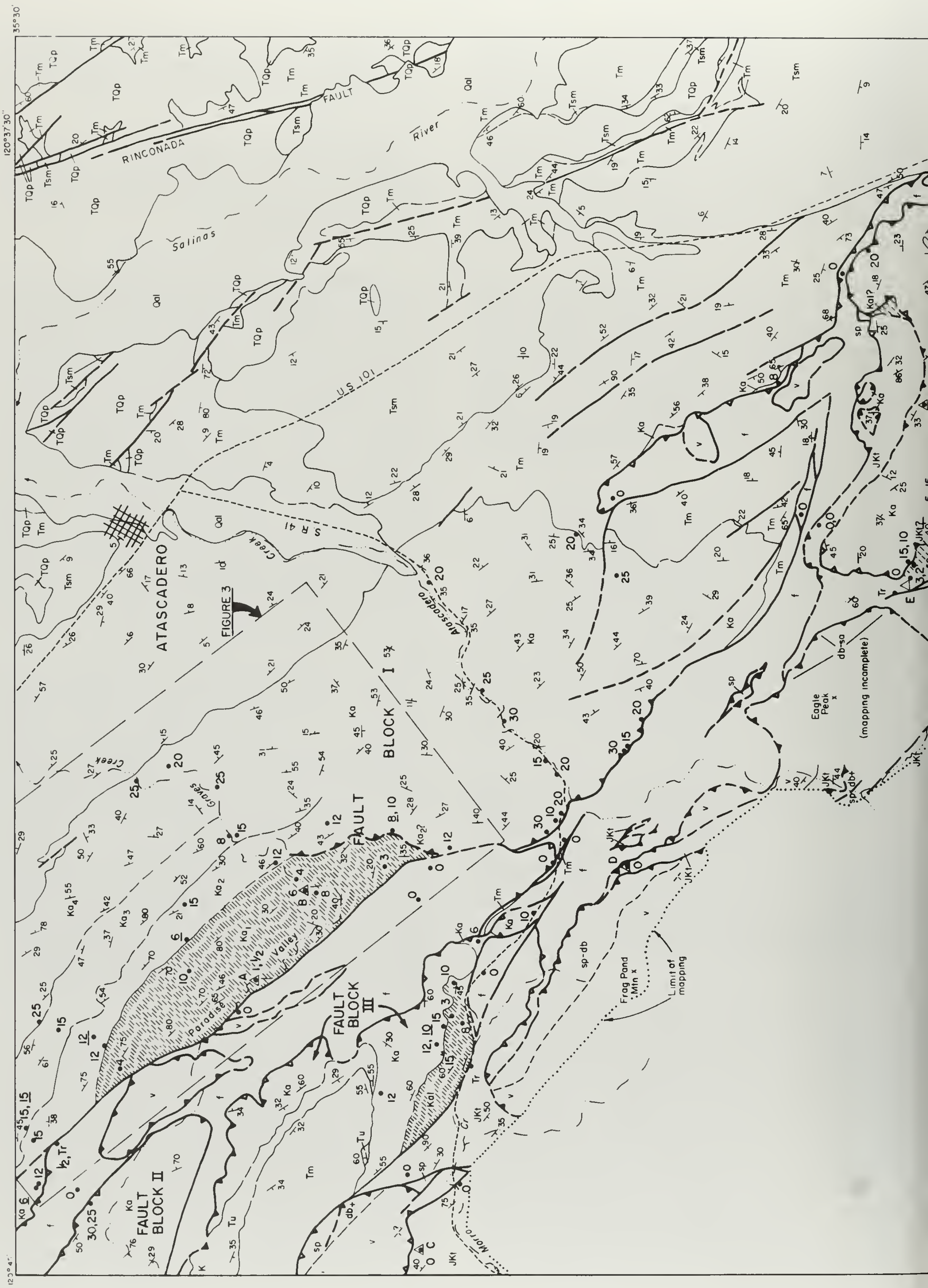
Lower and "upper" stratigraphic units also can be recognized locally in fault block IV (figure 2). However, these units are somewhat complicated structurally and the lower unit was not adequately mapped and sampled.

In summary, the Atascadero Formation as mapped consists of deformed and disrupted sequences distributed among four main fault blocks. The correlations of strata between fault blocks are obviously tentative and general, being based on petrologic and lithologic similarities, as fossils are scarce and marker beds absent. Further, the initial spatial positions and relations between the fault blocks are unknown. It therefore seems fruitless to attempt to interpret these partial sequences as part of a single stratigraphic unit that may never have been deposited in a common basin. Instead, the Atascadero beds, along with the Toro Formation, are viewed simply as parts of a larger Great Valley-like sequence deposited, with apparent stratigraphic gaps, in one or more sub-basins along a common continental margin—probably under varied and changing conditions.

Conditions of Deposition and Source of Sediment

The Great Valley-type sequences of the study area collectively show progressive and transitional changes, from the lowest beds, upward in several related aspects: (1) lithology, (2) conditions and type of sedimentation, (3) source of sediments. The widespread presence of turbidite sequences in the Toro and Atascadero Formations clearly indicate that most of the sediment was deposited in a basin(s) marginal to a large landmass (probably on a continental slope). Progressive changes in sediment character suggest a single provenance area that changed with time from one that was predominantly volcanic (mainly mafic) and sedimentary with no acid plutonic rocks (typical Toro Formation) to one that was largely silicic plutonic with subordinate volcanic ("upper" Atascadero Formation)—perhaps as suggested by Dickinson (1970).

Presumably most of the terrigenous sediment was derived from a growing magmatic arc that was progressively stripped of its volcanic cover to eventually expose its plutonic core. Such a magmatic arc presumably was associated with an active subduction zone. This latter is also evidenced by the Franciscan mélange (a subduction zone deposit) and by the ophiolites (former oceanic crust) present in the vicinity. Paleocurrent directions in the Atascadero Formation indicate an easterly or northeasterly sediment source area. Therefore, the proposed magmatic arc lay to the east and the subduction zone (trench) to the west.


35°30'
120°37'30"
RINCONADA
FAULT
Salinas
River
U.S. 101
ATASCADERO
FIGURE 3
S R 41
Creek
Atascadero
FAULT BLOCK I
FAULT
Graves
Creek
Paradise
Valley
FAULT BLOCK III
FAULT BLOCK II
Eagle Peak
(mapping incomplete)
Frog Pond Mtn
Limit of mapping
Morro

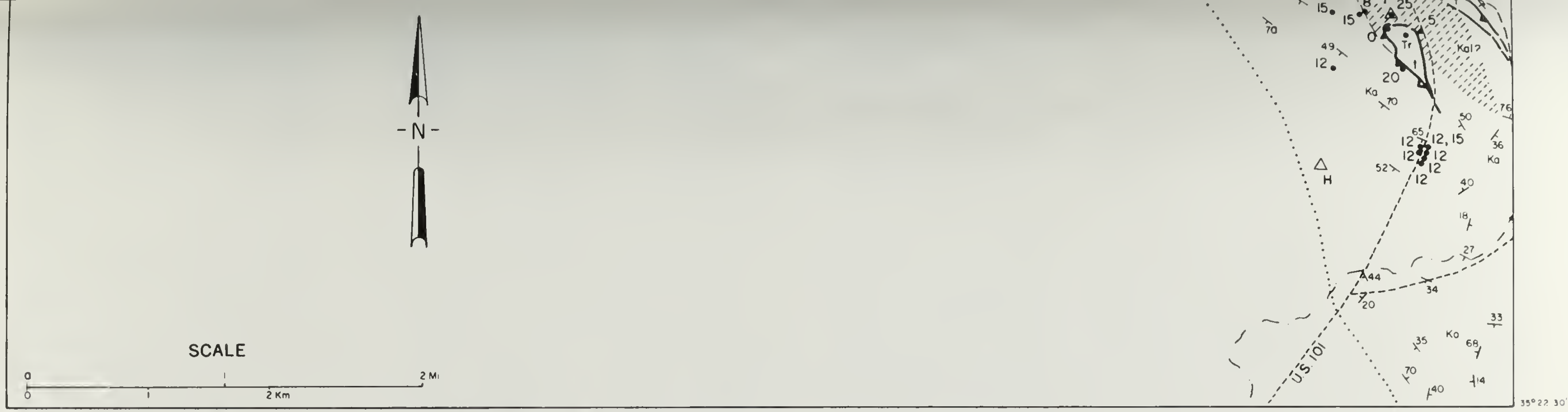


Figure 2. Geologic map of Atascadero area, California, showing K–feldspar contents of sandstone in upper Mesozoic units.

LEGEND

QUATERNARY	Qal	Alluvium (partly omitted)	
PLIO-PLEISTOCENE	TQp	Paso Robles Formation–nonmarine conglomerate, sandstone, mudstone	
MIOCENE	Tsm	Santa Margarita Formation – marine sandstone	
	Tm	Monterey Formation–marine shale with dolomite, sandstone, diatomite basalt	
OLIGOCENE	Tu	Unnamed nonmarine conglomerate and sandstone	
UPPER CRETACEOUS	Ka4, Ka3, Ka2, Ka1, Kal	Atascadero Formation-- marine sandstone, shale, mudstone, conglomerate; locally subdivided into lower beds (Kal) and "Paradise Valley sequence" (Ku1 to Ku4); lower beds shaded	Great Valley-type sequence
LOWER CRETACEOUS UPPER JURASSIC	JKt, JKt?	Toro Formation --marine shale with sandstone and conglomerate. Shaded area (JKt) is "atypical" K-feldspar-bearing sandstone and mudstone	Great Valley-type sequence
UPPER JURASSIC	v	Mafic volcanic rocks-includes chert, shale(?) mafic dikes and sills (?)	Ophiolite sequence
	db / sp	Serpentine (sp) with intrusive diabase (db) and related rocks	Ophiolite sequence
CRETACEOUS-UPPER JURASSIC	f	Franciscan melange	

SYMBOLS

8•	K-feldspar content of sandstone samples in percent (whole rock); Tr = trace; underline shows very abundant calcite (20-50%)
A △	Fossil localities (see table I)
	Normal contacts; dashed where approximate or inferred
	Faults, dashed where inferred; barbs on upper plate of thrust faults
	Main roads
	Main streams
35	Bedding attitude; broken symbol shows approximate attitude

The precise sedimentary and morphologic conditions prevailing at a given time are unknown, although a general range of conditions can be surmised by comparison with modern ocean and continental margins. Most of the eastern Pacific Ocean margin, for example, is bordered by active trench–magmatic arc systems where oceanic crust is underthrusting the continental margins. The continental slope between the trench and the arc is invariably broken into one or more intervening ridges and troughs (sub–basins)—generally by high–angle faults (e.g., Ross and Shor, 1965; Scholl and others, 1970; Silver, 1971). Acoustic profiles show that the upper basins of such slopes tend to act as sediment traps, inhibiting terrigenous sedimentation on the lower parts of the slope. They also reveal that some of the Cenozoic strata are somewhat deformed and that unconformities (stratigraphic gaps) are common.

In that context, it seems likely that most of the Toro Formation was deposited along a lower or outer part of a continental slope where hemipelagic sedimentation alternated with coarse terrigenous sediment of turbidity current origin. The thin basal Toro, in contrast, contains radiolarian chert (formerly ooze?) and siliceous shale resting on mafic volcanic rocks, which probably represents pelagic and hemipelagic sedimentation on oceanic crust under abyssal(?) conditions. A transition from abyssal(?) to continental slope conditions during early Toro time seems possible, although the mechanics of such a change are not clear. Perhaps the transition marks the initial development of a trench to the west.

The "upper" Atascadero beds, being mainly coarse terrigenous sediments and partly of shallow–water(?) origin, suggest upper (inner) slope basin and shelf(?) conditions. The lower Atascadero beds, being intermediate in lithologic character and age between the Toro and typical ("upper") Atascadero rocks, suggest a transition from outer deep–water (distal) conditions to relatively shallow, near–shore (proximal) conditions. Very likely, then, the upper Mesozoic strata near Atascadero were deposited under varied and more or less progressively changing conditions along a tectonically active continental margin between an active trench on the west and a developing magmatic arc on the east. Whether deposition was within a single basin, as suggested for the Great Valley sequence east of the Salinian block (Dickinson, 1971), cannot be stated with assurance. Based on modern analogs, most tectonically active continental margins contain one principal basin of deposition. Probably, the basin(s) of deposition underwent simultaneous sedimentation and deformation during trench–arc development.

K–FELDSPAR CONTENT OF SANDSTONE

Sampling

During the course of detailed mapping, 106 samples of sandstone were collected for K–feldspar staining from three upper Mesozoic units—Toro Formation (Upper Jurassic to Lower Cretaceous), Atascadero Formation (Upper Cretaceous), and Franciscan melange (figure 2). Because of discontinuous outcrops, structural deformation, and the presence of graywacke in all units, off–hand distinction among these three units is not always easy or even possible. As a result, the map units are somewhat interpretive. To check these interpretations, representative sandstone samples were stained for feldspar. Approximately seventy samples were also thin–sectioned for petrographic examination.[1] Because of the structural and stratigraphic complexities and limited outcrops, no attempt was made to sample the map units in a statistically representative manner. Instead, samples were obtained to solve specific problems and to test the assumption that the K–feldspar contents varied systematically with age (Bailey and Irwin, 1959).

Most of the samples were taken from the Atascadero Formation of fault block I, because the northern part of that block—the "Paradise Valley sequence"—seemed to be more stratigraphically intact than the other fault blocks. An effort was made to sample each stratigraphic subdivision in that fault block. Enough samples were obtained elsewhere, and it is believed that the samples collectively represent the spectrum of sandstone types present in the three upper Mesozoic units.

Based on the samples collected and analyzed, certain conclusions can be drawn. The validity of the conclusions probably would not be significantly changed with additional K–feldspar–stained samples alone. The lack of diagnostic fossils and the absence of thick intact stratigraphic sequences are more important to drawing valid conclusions.

Most of the sandstone samples are medium grained, a few are fine grained, and some are coarse. The samples also vary considerably in grain–size distribution, amount of matrix or cement, degree of weathering, and diagenetic alteration. These factors could not be entirely anticipated or controlled at the outcrop, and they may have an effect on the amount of K–feldspar estimated to be present (see "Staining Methods").

Staining Methods

The contents of K–feldspar were estimated from small slabs of sandstone stained with sodium cobaltinitrite, using a technique similar to Bailey and Irwin (1959). Briefly, all samples were slabbed with a water–cooled diamond saw and polished on a lap–wheel. Flexible Collodion (mixed 1:1 with alcohol) was used to seal the intergranular area before the final lap polish (#400 grit). A slab was then etched with hydrofluoric acid and dipped in water to remove excess acid. This was followed by immersion of the polished face in saturated cobaltinitrite and rinsing. The slab was then dried. Final sealing of the stained surface with

[1] Stained samples and thin sections are on file with the California Division of Mines and Geology, Ferry Building, San Francisco

clear acrylic lacquer protected the stain from flaking and improved the color contrasts between grains, which made estimation easier.

A bright yellow to orange-yellow stain was obtained on the potash feldspar grains. Other potash-bearing minerals (e.g., micas) stained a paler yellow, but these mineral grains are readily distinguished from K-feldspar. A few grains of what appeared to be devitrified volcanic glass also stained yellow (usually pale). The great bulk of stained grains are monomineralic, although some are polymineralic rock fragments (e.g., felsite, aplite, sandstone).

Estimation of K-feldspar Content

The stained slabs were viewed through a binocular microscope, the magnification being adjusted to the grain size. Estimates of detrital K-feldspar present were based on the percentage of area stained yellow, which approximates the volumetric percentage of K-feldspar in the whole rock. Estimates were made by comparison with the visual estimation charts of Terry and Chilingar (1955, p. 229-234) and by comparing the slabs with each other. Several samples of varying K-feldspar content were point-counted (300-400 counts per slab) to verify the accuracy of the estimates. All estimates were made by this writer to assure uniformity. Spot estimates by other operators also were made to check operator-accuracy.

Contents of K-feldspar were estimated to the nearest appropriate number on the following percentage scale: O,Tr, 0.5, 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 25, and 30%. The accuracy of these estimates cannot be measured properly because of the limitations of point-counting an etched surface. Such a surface has a micro relief due to the loss (plucking) of grains and/or matrix-cement. The effect of this loss on estimates of K-feldspar content depends on whether selective plucking of grains occurred or whether selective removal of interstitial material exposed an anomalously high percentage of grains. For the purposes of this study, the method of estimating is considered sufficiently accurate (within oneor, at most, two numbers of the percentage scale used) to reveal orderly variations in K-feldspar contents.

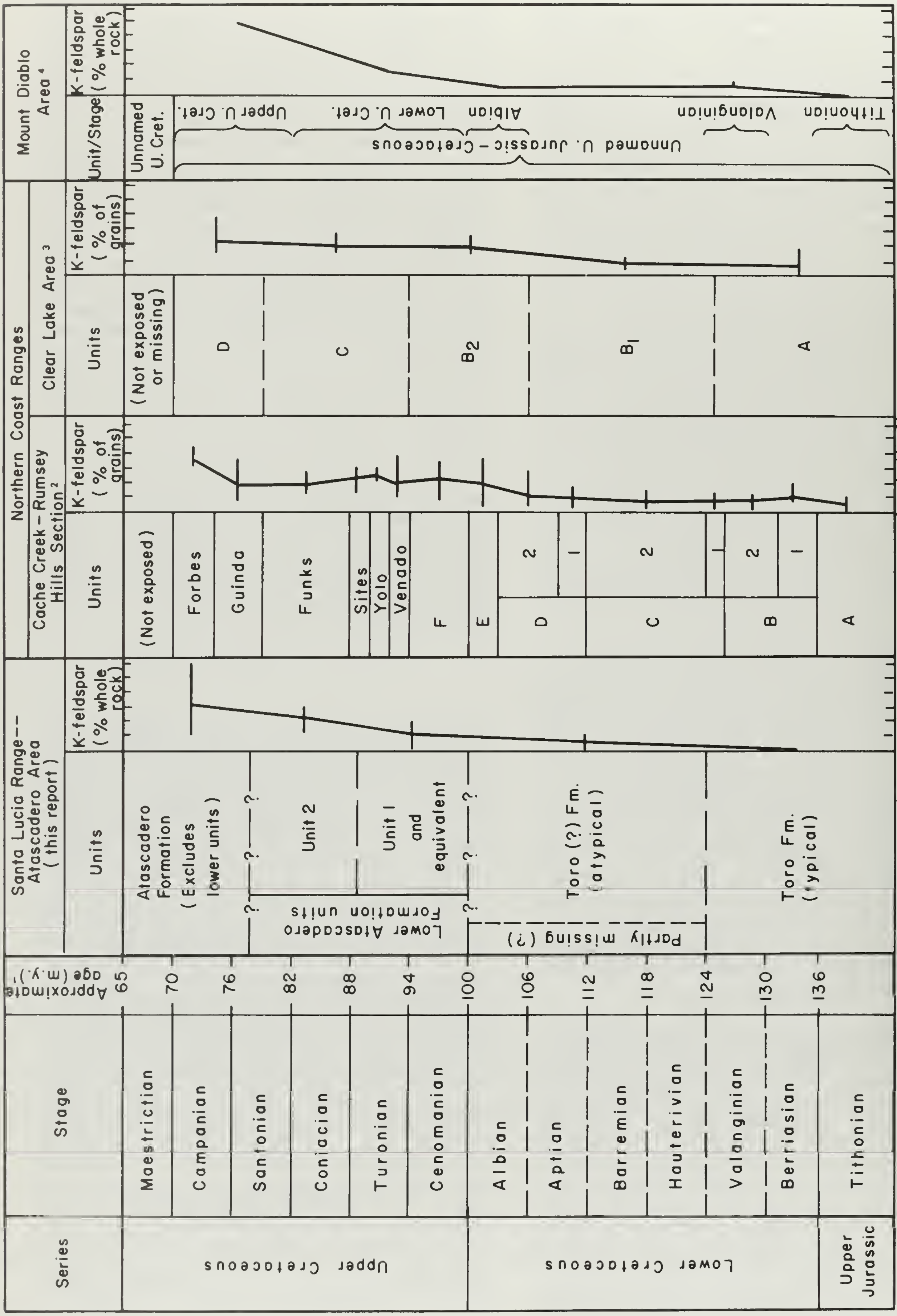
Factors that can affect the K-feldspar content include grain size, amount of interstitial material, and diagenetic changes. Somewhat lower percentages of K-feldspar were observed in fine-grained sandstone, partly because of increased matrix. In one graded sandstone, K-feldspar was clearly more abundant in the coarse-grained portion than in the fine. In samples containing abundant calcite cement, K-feldspar estimates generally were lower than anticipated. Three samples with "anomalously" low K-feldspar contents were found to contain 30 to 50% calcite in thin section. Several other samples also contained abundant calcite. Thin-section examination reveals that all highly calcareous sandstones showed extensive etching and calcite replacement of most grains, including quartz and feldspars (especially plagioclase). Other types of replacement (e.g., albitization, chloritization) may occur selectively and affect observed feldspar contents. Even with nonselective replacement of framework grains, the ratio of framework grains to whole rock decreases, thereby decreasing the percentage of K-feldspar in the whole rock. In the case of seven paired samples (i.e., samples from adjacent localities and approximately from the same stratigraphic position) where only one sample contained abundant calcite, the calcite-rich sample contained less K-feldspar than its paired counterpart in five cases and more K-feldspar in only one case. In a few samples, matrix (mainly phyllosilicates) appears to make up a large part of the whole rock, thereby reducing the effective amount of K-feldspar present in the rock. Secondary K-feldspar conceivably could give anomalous results. However, secondary fracture fillings and replacements of grains or matrix were not observed in the study area.

Anomalously high estimates of K-feldspar may result from fine-grained silicic volcanic rock fragments (e.g., devitrified glass, felsite). Such grains usually stain pale yellow and may be banded or granular. When detected, they were excluded from the estimates. K-feldspar in coarse-grained admixtures (e.g., aplite, granitic fragments), however, was included in the estimates.

Results

Estimations of K-feldspar contents of the 106 selectively stained samples are shown on figure 2. The distribution of K-feldspar contents in sandstone samples,by map units, is summarized in table 2. This summary shows the range, mean, and median for each map unit and its components. Figure 4 compares these data with K-feldspar data obtained for the Cache Creek-Rumsey Hills section (Ojakangas, 1968, figure 10) and other areas where the Great Valley sequence is well ordered and more or less complete. The frequency distribution of K-feldspar in the three principal map units is given in the histogram (figure 5).

Fourteen samples of graywacke indicate the Franciscan mélange, as mapped, contains little or no K-feldspar. Only one sample of relatively undeformed greenish-gray graywacke contained as much as 0.5% K-feldspar. If the lack of K-feldspar is a reflection of age, as it seems to be for the Great Valley-like rocks, then much of the Franciscan in the study area would appear to be Early Cretaceous or older. This conclusion is based on the assumption that the Franciscan and Great Valley-type rocks have a common source region. The presence of larger amounts of K-feldspar in the Franciscan elsewhere in the Santa Lucia Range (Bailey and others, 1964, plate 2) may indicate a younger age for that unit in other areas. The significance of this, however, may largely depend on how the Franciscan is defined.



[1] Radiometric ages in million years (m.y.) (after Harland and others, 1964).
[2] Ojakangas (1968, figure 10).
[3] Swe and Dickinson (1970, table 1).
[4] Colburn (1961, p. 14–15).

Figure 4. Distribution of means and ranges (horizontal lines) of K–feldspar content of sandstone in map units of Great Valley–type strata near Atascadero, Santa Lucia Range, compared with Great Valley sequences east of the Salinian block.

Table 2. K-feldspar content of sandstone samples of upper Mesozoic sandstone units near Atascadera (see figure 2 for sample locations and analyses).

Map unit	Number of samples	Estimated Content of K-feldspar (in percent by volume) Range	Mean	Median
Atascadero Formation ..	75 — –	0.5–30%	13.9%	–
Fault block I	— 43 –	0.5–30	14.6	–
"Paradise Valley sequence"				
Units 3 and 4.............	— — 9	8–25	18.1	15%
Unit 2	— — 10	6–15	11.4	12
Unit 1	— — 8	0.5–10	4.6	4
Undifferentiated.........	— — 16	6–30	19.1	20
Fault block II	— 2 –	25–30	27.5	–
Fault block III	— 10 –	3–15	10.1	10
Upper unit...................	— — 6	10–15	12.3	12
Lower unit...................	— — 4	3–10	6.8	–
Fault block IV	— 20 —	5–20	13.4	12
Toro Formation	17 — —	0–5	1.2	Tr
Atypical (upper?; near Eagle Peak) [1]	— 7 –	1–5	3.0	3
Typical [2]	— 10 –	0–Tr	Tr	0
Franciscan melange........	14 — —	0–0.5	Tr	0
Total samples	106			

[1]Fine- to medium-grained, gray to greenish-gray sandstone and mudstone; highly deformed; no fossils.

[2]Associated with typical dark shale and *Buchia*-bearing chert-pebble conglomerate.

The Toro Formation contains little or no K-feldspar in ten samples of lithic graywacke associated with typical chert-pebble conglomerate and dark shale. Three of these samples are from beds containing diagnostic fossils of Valanginian (Early Cretaceous) age and older (figure 2 and table 1).

Atypical deformed strata of the Toro Formation (?) about a mile southeast of Eagle Peak show small but distinct amounts of K-feldspar, with an average of 3% for seven samples. Because this sequence overlies typical Toro rocks of Valanginian age, the atypical beds are presumably younger. This presumption fits well with the notion that K-feldspar increases in abundance with decreasing age. If so, this may represent the first significant influx of K-feldspar during late Mesozoic time. However, the atypical Toro sequence is deformed and nonfossiliferous and may be in fault contact with the typical Toro. Petrologically, it is similar to the "Paradise Valley sequence" (unit 1) of early Late Cretaceous age. In any event, no firm conclusion can be drawn as to the meaning of the K-feldspar content of this atypical unit as its age is not

Figure 5. Histogram showing percentage frequency distribution of K-feldspar in 106 samples of upper Mesozoic sandstone.

known. Nonetheless, it is pointed out that the Toro Formation just west of the mapped area is reported to contain Upper Cretaceous palynomorphs by Gilbert and Dickinson (1970, p. 950–951) in their equivalent "lower Great Valley unit". They also report about 5% K-feldspar in a sandstone sample from the same area.

The distribution of K-feldspar contents in the Atascadero Formation can be interpreted in different ways. Taken collectively, the seventy-five Atascadero sandstone samples show a range of 0.5 to 30% and a mean content of 13.9% K-feldspar (table 2). This clearly distinguishes the Atascadero from the Toro Formation, which has a range of 0 to 5% and a mean of only 1.2%.

If the K-feldspar samples of the Atascadero Formation map units are grouped into a composite lower unit (unit 1 of fault block I and lower unit of fault block III) of twelve samples and an upper unit (all other Atascadero Formation rocks) of sixty-three samples, then mean contents of 5.3% and 15.5% K-feldspar are obtained. The Atascadero samples can be grouped into other upper and lower combinations with similar results—the lower unit always showing less K-feldspar than the upper one. So, the "lower" and "upper" parts of the Atascadero Formation, together with the Toro Formation, show a general but systematic increase in K-feldspar with decreasing age. As the Atascadero cannot be related positively to a single stratigraphic sequence, a more precise systematic relationship between K-feldspar distribution and stratigraphic position (or time) is difficult to demonstrate. However, some light can be shed by examining the individual fault blocks in some detail.

The northwest half of fault block I yields the best data because it contains the relatively well-preserved "Paradise Valley sequence" (units 1 to 4) (figure 3). Figure 2 and table 2 show that units 1 to 4 increase progressively in K-feldspar content with changing stratigraphic position (and, therefore, age). The principal increase is in unit 1, which has a range of 0.5 to 10% and a mean content of 4.6% for eight samples. Unit 2 shows a mean of 11.4% and units 3 and 4 (combined because only nine samples are represented) a mean of 18.1% The undifferentiated rocks elsewhere in the fault block are largely similar to units 3 and 4, and they show a mean of 19.1% K-feldspar. Unfortunately, only the basal part of unit 1 contains diagnostic fossils (Cenomanian–Turonian). Although the upper units are similar to uppermost Cretaceous fossiliferous strata of fault block IV, an uppermost Cretaceous age cannot be proved for units 3 and 4.

The same stratigraphic change in K-feldspar content is shown in fault block III, the lower unit (unit 1?) having a mean content of 6.8% and the upper unit a content of 12.3%. No fossils were found here and only the south part of the fault block was sampled.

Fault block IV was not sufficiently sampled to show the K-feldspar distribution between upper and lower

units—partly because of structural complexities. Twenty samples from this unit averaged 13.4% K–feldspar, but no systematic distributionis recognizable. The lower Atascadero sequence of mudstone and thin-bedded sandstone, exposed in the northeast part of the fault block, was not sampled adequately and probably is represented only by two samples near U.S. Highway 101 (5% and 8% samples) where the beds are highly disturbed and faulted.

Diagnostic fossils (localities G and H, table 1) indicate a Campanian–Maestrichtian age for all or most of the upper part of fault block IV. Gilbert and Dickinson (1970) identify this fault block as "upper Great Valley unit" and fault block I (excluding units 1 and 2) as "middle Great Valley unit" on the basis of petrology. Superficially, fossil data would seem to confirm this relationship. However, if the assumption of increasing K–feldspar content with decreasing age is employed,then fault block IV should be equivalent to, or slightly older than, all post–unit 2 rocks of fault block I. It seems unlikely that a confident age correlation can be made between the two fault blocks because of structural and stratigraphic problems. Most likely, both blocks contain strata of somewhat varying and overlapping ages.

The precise times of K–feldspar increase cannot be identified for the Great Valley–type sequences of the study area because of fragmented sequences and scarcity of diagnostic fossils. However, the data in table 2 and figure 4 show that the principal increase in K–feldspar occurred during late Cretaceous time. The first definite appearance of K–feldspar is recorded about Cenomanian–Turonian time. By Campanian time, K–feldspar was very abundant and constitutes 10% or more of the sandstones (with minor exceptions). Earlier increases have not been clearly documented, although all typical Toro Formation samples associated with Tithonian to Valanginian fossils contain little or no K–feldspar. The atypical nonfossiliferous K–feldspar–bearing Toro may prove to be post–Valanginian and possibly early Late Cretaceous in age.It is clear that more information is needed on the relationship between fossil–dated sequences and K–feldspar content to be able to provide a more precise understanding of K–feldspar as an age indicator in the Santa Lucia Range.

Time–distribution comparisons of K–feldspar increase with other Great Valley sequences east of the Salinian block are given in figure 4. The complete and intact sequence in the Cache Creek–Rumsey Hills section shows small amounts of K–feldspar present throughout the Upper Jurassic–Lower Cretaceous section with sharp increases in content during the Albian and Campanian Ages. The K–feldspar increases are attributed mainly to unroofing of plutonic rocks (Ojakangas, 1968).

Another comparison can be made with Great Valley–type strata near Mount Diablo, where Colburn (1961) sampled and reported the following K–feldspar averages for sandstones: Upper Jurassic, trace; Valanginian and Albian, 3%; lower Upper Cretaceous, 8% uppermost Cretaceous, 25%. Adequate K–feldspar data are not available for equivalent strata along the west side of San Joaquin Valley. Limited sampling by C.C. Bishop (1970, personal communication) in Hospital Creek indicates that K–feldspar makes its first significant appearance in Albian to Turonian rocks (Adobe Flat Member, Panoche Formation) and is very abundant in Campanian rocks. West of Coalinga, the Campanian rocks are reported (Mansfield, 1971) to contain about 20% K–feldspar and Tithonian to Turonian rocks 1–6%.

It seems evident that K–feldspar appears earlier (Late Jurassic) and is more abundant in Early Cretaceous time in the northern Coast Ranges than in the Atascadero area. Also, significant amounts of K–feldspar appear earlier (Albian) in the Cache Creek–Rumsey Hills area than the study area (Cenomanian–Turonian). All areas, however, record large amounts of K–feldspar by Campanian time.

Despite the compositional variations in equivalent–age strata from place to place in the Coast Ranges, it is quite apparent that Great Valley–type rocks everywhere reflect a general upward increase in K–feldspar content. Although Bailey and others (1964, p. 139) state, "K–feldspar content may locally provide a crude method for determining the probable age of unfossiliferous late Mesozoic strata in the Coast Ranges", their sample data (1964, plate 2) do not clearly substantiate this for strata west of the Salinian block. This study, however, does support their general assumption, although the time–distribution of K–feldspar in upper Mesozoic sandstones near Atascadero differs somewhat with the northern Coast Ranges. Therefore, until other fossiliferous sequences can be sampled, it is suggested that the Atascadero area be used as a local reference to estimate the approximate age of late Mesozoic strata elsewhere in the Santa Lucia Range.

SOURCE OF K–FELDSPAR

The great bulk of K–feldspar identified in stained slabs and thin sections of Cretaceous sandstone is monomineralic or nearly so. Most of the K–feldspar is presumed to be orthoclase, as the great majority of optically oriented untwinned grains examined have a large 2V. Only a few grains of sanidine (small 2V) were identified. Small but persistent amounts of perthite and microcline were identified. Although alteration products and random grain orientations prevent a precise determination, it is inferred that the K–feldspar consists mainly of orthoclase, with subordinate amounts of perthite, microcline, and sanidine (listed in order of estimated decreasing abundance).

This assemblage of K–feldspar mineral grains (other grains excluded) is most suggestive of a pluton-

ic source (especially an acidic one) with a very subordinate volcanic source. A significant sedimentary source is largely precluded by the immature textures and compositions that dominate all sandstones examined. A metamorphic source of K-feldspar is possible, but most metamorphic grains suggest low-grade metamorphism (e.g., greenstone, metachert, phyllite). Intermediate-grade metamorphic rock grains (quartzite, quartz-mica schist) are present only in small amounts.

The over-all granular composition of typical feldspathic sandstone of the upper part of the Atascadero Formation also indicates a chief acid plutonic source (e.g., quartz monzonite or potassic granodiorite). Lithic grains, however, reveal a significant, although subordinate, volcanic source and minor metamorphic and sedimentary sources. These sandstones contain roughly equal amounts of quartz (mostly monocrystalline, but some is coarsely sutured or mosaicked), plagioclase (mostly twinned anhedral grains, commonly oligoclase), and K-feldspar (as indicated above) with about 5% large ragged flakes of partly chloritized biotite. Lithic and other grains usually amount to less than 20% of the grains. The large arkosic fraction strongly suggests an acid plutonic source.

Lower parts of the Atascadero Formation, such as units 1 and 2 of "Paradise Valley sequence" (lower Upper Cretaceous), contain more volcanic (mafic and silicic) and metavolcanic debris and correspondingly less K-feldspar. Nonetheless, a major plutonic source is indicated by the K-feldspar minerals and the associated monocrystalline quartz and "anhedral" plagioclase grains. The older Toro Formation sandstone reflects principally volcanic and sedimentary (partly metamorphosed) sources and a near absence of K-feldspar.

The increasing abundance of K-feldspar with decreasing age, noted above, seems to be due to an increasing availability of acid plutonic rocks in the source area. It is uncertain whether this availability is due solely to progressive unroofing of acid plutonic rocks or is partly the result of successive emplacements of progressively more acidic (i.e., potassic) plutons.

Paleocurrent data from Upper Cretaceous rocks indicate that the source area(s) lay to the east or northeast (McClure, 1969) in the direction of the Salinian block. Compton (1966) shows that much of the block in the southern Coast Ranges consists chiefly of acid plutonic rocks. Associated are more mafic plutonic rocks (especially biotite quartz diorite) and medium- to high-grade metamorphic rocks, which are abundant in the northern Santa Lucia Range and northern Gabilan Range but relatively uncommon elsewhere in the southern Salinian block. Volcanic rocks comparable to debris in the Great Valley-type rocks are not exposed and probably have been stripped from the Salinian block or were derived from a region that formerly lay to the northeast (i.e., before being offset along the San Andreas fault).

A specific plutonic source area in the Salinian block is difficult to identify because biotite granodiorite and quartz monzonite are so widespread. In the western La Panza Range, due east of the study area, nineteen samples (stained slabs, including seven thin-sections) were collected and studied. These were found to form a gradational series—eleven being potassic granodiorite and eight quartz monzonite. The compositional ranges (and averages) are as follows: quartz, 23.8–39.1% (30.2%); plagioclase, 32.5–48.9% (41%); K-feldspar, 11.1–32.3% (20.4%); and biotite, 2.6–12.3% (7.7%). The quartz is interstitial, commonly occurring as sutured, mosaicked intergrowths. It also exists as myrmekitic intergrowths with the feldspars. Plagioclase, which is commonly zoned, is mainly oligoclase to sodic andesine. The K-feldspar is largely untwinned orthoclase, generally present as phenocrysts with abundant inclusions. Microcline is rare. A minority of the K-feldspar is perthitic. Biotite is strongly pleochroic and partly chloritized. Sphene, apatite, and muscovite make-up less than 1% of the rock. Similar quartz monzonite and biotite granodiorite greatly predominate throughout the La Panza Range (Compton, 1966, p. 277; Ross, 1972). Aplite and pegmatite dikes commonly cut these granitic rocks. Inclusions of marble, schist, quartzite, and gabbro indicate the existence of a former sedimentary terrain, as well as possible mafic plutonism.

The principal minerals and small-scale textures present in the La Panza granitic rocks can be recognized in sandstones of the Atascadero Formation more or less in the same proportions. It is, therefore, tempting to assume that the La Panza granitic rocks are the source of most of the K-feldspar and most other nonlithic grains that constitute the sandstones. However, the granitic rocks of the La Panza Range may not be unique in the southern Salinian block (Ross, 1972).

To test the La Panza Range as a specific source area, it is necessary to examine (1) possible large-scale lateral displacements and (2) the age of the plutonic rocks. To permit examination, it is assumed that the former coast of the source region trended roughly northwest (i.e., parallel to the Sur-Nacimiento fault zone).

Lateral displacement of the Great Valley-type rocks relative to the Salinian block may have occurred and bear on the provenance location. Displacements normal to the block probably are of nominal significance, as continental slope sediments tend to be dispersed downslope in a gross way. Lateral displacements of a large order parallel to the block would be significant, however; but offsets of large magnitude of the San Andreas type are not known for this area. The only important strike-slip fault identified between the map area and the La Panza granitic

rocks is the Rinconada fault, which joins the Jolon and other faults to the northwest (figure 1). An apparent right–lateral offset of 33 miles is interpreted for this fault since late Oligocene or early Miocene time (Hart, 1971 and 1976). This interpretation is consistent with Dibblee (1972), who estimates a maximum right–lateral displacement of 40 miles along the "Rinconada" fault since Cretaceous time.

If no other large lateral displacements have occurred along undetected northwest–trending faults or along the Rinconada fault prior to Tertiary time, then the Great Valley–type rocks of the study area apparently had a source centering in the southern La Panza Range—an area now covered by a thick sequence of clastic marine sedimentary rocks of latest Cretaceous to Eocene age. This sequence rests unconformably on granitic rocks, exposed in the northern part of the La Panza Range, and shows southerly and southwesterly paleocurrent directions (Chipping, 1972).

The age of the Salinian granitic rocks is uncertain because of somewhat anomalous radiometric age determinations. A minimum age of 70 to 72 m.y. is placed on the La Panza granitic rocks by the unconformably overlying Upper Cretaceous (upper Campanian, D–2 zone) beds southeast of Atascadero. The maximum age is uncertain because of limited and anomalous results indicated by radiometric age dating.

Radiometric dates on granitic rocks of the La Panza range from 54.5 to 83 m.y. (Hart, 1971 and 1976; Evernden and Kistler, 1970, plate 2). Elsewhere in the southern Coast Ranges, dates of 67 to 117 m.y. have been determined by potassium–argon, fission track, and rubidium–strontium methods (Evernden and Kistler, 1970; D.C. Ross and C.W. Naser, 1970, personal communication). Except for the 117 m.y. rubidium–strontium date, all determined ages are considered to be minimum.

Based on stratigraphy and age–dating techniques, a minimum age of Coniacian to Santonian (mid–Late Cretaceous) is indicated for the granitic rocks of the La Panza Range. The older dates determined for other parts of the southern Coast Ranges suggest a possible maximum age of mid–Early Cretaceous (Barremian). Evernden and Kistler (1970, p. 17, 22) state that the potassium–argon ages obtained in the Coast Ranges plutons are anomalously low with respect to the ages determined by other techniques. They consider the "reduced" ages to be due to a "combination of burial and abnormal heating and strain prior to the exposure of the plutons". The Coast Ranges plutons are correlated with their "Huntington Lake intrusive epoch", which they state has a time span of 104 to 117 m.y.

Petrologic, paleocurrent, radiometric, structural, and other geologic data, considered together, strongly indicate that the southern La Panza Range area lay opposite the Atascadero area and that part of the Salinian block was the chief source of K–feldspar and related granitic sediment during late Cretaceous time.

Beds of the lower Atascadero Formation record the apparent initial influx and progressive increase in K–feldspar–bearing granitic debris. This change is correlated with progressive plutonic unroofing. The increase in K–feldspar appears to be accompanied (or slightly preceded) by a shift from dominantly mafic to silicic volcanic debris. This may suggest a genetic relation between the silicic volcanic and K–feldspar–bearing granitic rocks. If so, plutonic emplacement may have been shallow, with only a short interval between volcanism and initial unroofing. Although stripping of the volcanic cover from the granitic rocks undoubtedly was progressive, volcanic grains in the sandstone and predominant volcanic clasts in the conglomerate indicate that volcanic rocks persisted in the source area during latest Cretaceous time. Similar volcanic rocks are no longer exposed in the Salinian block.

CONCLUSIONS

1. The distribution of K–feldspar in sandstones of the Great Valley–type strata near Atascadero demonstrates that K–feldspar content systematically increases with decreasing age in a general way as follows: (1) Late Jurassic (Tithonian) to Early Cretaceous (Valanginian), zero to a trace; (2) early Late Cretaceous (Cenomanian–Turonian or a little later), 0.5 to 10%; (3) latest Cretaceous (Campanian–Maestrichtian), 10 to 30%. It seems probable that the K–feldspar increase is related to progressive, and perhaps rapid, unroofing of the plutonic rocks of the Salinian block. The rapid increase in K–feldspar and apparent corresponding increase in silicic volcanic detritus suggest that shallow plutonic emplacement may have closely preceded unroofing. It also may suggest the volcanism stopped or subsided enough to permit the plutonic rocks to be unroofed.

2. The K–feldspar content of sandstone can be used much like fossils to estimate the approximate age of a given rock sequence and to crudely correlate between sequences. The determination of K–feldspar in sandstone, although only one measure of over–all composition, is much more rapid and less tedious than petrographic modal analysis, which also has been used for correlation (e.g., Swe and Dickinson, 1970; Gilbert and Dickinson, 1970). However, the use of K–feldspar as a precise indicator of time or tool of correlation is unrealistic because of the inherent variations in content related to source areas, grain size, amount of matrix or cement, and diagenetic changes (replacement and authigenic growths). In a given bed or a closely related sequence of beds, contents may vary by a

factor of two or three. Changes in K–feldspar content with stratigraphic position are not always progressive in detail—even through thick sequences—as shown by Ojakangas (1968; figure 4 herein).

3. The age of the Franciscan mélange can be approximated if it is assumed that (1) the Franciscan is a subduction zone product formed by the convergence of two lithospheric plates during the deposition of the Great Valley–type sediments to the east and that (2) the K–feldspar distribution in the Great Valley–type sequence is also reflected in the Franciscan sandstones (trench deposits?). Since all but one sample of Franciscan sandstone contained no more than a trace of K–feldspar, it is suggested that the mélange, as mapped, is mainly of Valanginian (or Cenomanian–Turonian?) age and older. If Upper Cretaceous sandstone units of the Atascadero Formation are part of the melange, then either the K–feldspar was eliminated from the younger rocks or the Upper Cretaceous units surrounded by mélange were "mapped out" of the Franciscan because of their relative coherency. Compatible with a Late Jurassic–Early Cretaceous age for the Franciscan mélange is the abundance of tectonic inclusions of the Toro–like and ophiolitic rocks and absence of the Upper Cretaceous rocks. The latter appears to be tectonically mixed with the Franciscan to an extent no greater than the Tertiary rocks, suggesting that Tertiary deformation may be largely responsible for local tectonic incorporation of Upper Cretaceous rocks into the Franciscan.

4. Comparison of Great Valley–type strata near Atascadero with the Great Valley sequence of northern California indicates that abundant K–feldspar appears much later (post–Valanginian or Cenomanian–Turonian) in the study area. Plutonic rocks were contributing about half of the debris for the sandstones of earliest Cretaceous rocks of the Cache Creek–Rumsey Hills area of northern California (Ojakangas, 1968, p. 989), whereas equivalent strata near Atascadero received little plutonic (and certainly no acid plutonic) debris. Although early volcanic (especially mafic) activity is clearly indicated for the Salinian source area, acid plutonic "roots" of the probable volcanic arc apparently were not unroofed (and probably were not emplaced) until after Valanginian time. Whether this same relationship holds for the rest of the Santa Lucia Range is uncertain. However, until adequate sample data indicate otherwise, K–feldspar data from the Atascadero area probably can be applied to unfossiliferous Great Valley–type rocks elsewhere in the Santa Lucia Range. Increased confidence and a finer subdivision would have to be based on local controls established in fossiliferous sequences. Also, it is recommended that crude K–feldspar age assignments be based on more than one sample, especially for transitional rocks of "middle" Cretaceous age.

5. The source area of the K–feldspar–bearing Cretaceous strata of the Atascadero area appears to have centered somewhere in the southern La Panza Range. The lack of K–feldspar in the typical Toro Formation indicates that any K–feldspar–bearing plutonic rocks that may have existed had not been unroofed in the source area until after Valanginian time. The first definite appearance of abundant K–feldspar occurred about Cenomanian–Turonian time. (Alternately, it may indicate a Late Cretaceous age for the "atypical" Toro.) Modest amounts of K–feldspar in nonfossiliferous "atypical" Toro Formation may indicate initial unroofing possibly as early as late Early Cretaceous (post–Valanginian) time. These ages are in agreement with maximum age dates of 117 m.y. or younger for the plutonic rocks of the southern Coast Ranges. A lack of fossils and probable absence of much of the middle Cretaceous section prevents a more precise interpretation of plutonic events and unroofing. Widespread unroofing of the plutons of the source area probably took place about Campanian time, although volcanic rocks were still abundant in the source area at this time.

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APPENDIX

Fossil Localities

Locality A

Sample No.: SLO 247
Location: In Graves Creek, 7,200 feet S. and 8,700 feet E. of NW corner Atascadero quadrangle.
Map Unit: "Paradise Valley sequence" unit 1, Atascadero Formation.
Collected by: E.W. Hart
Identified by: D.L. Jones, U.S. Geological Survey, Menlo Park, Calif.
Description: "A wide variety of forms are present, but most identifications are questionable due to the small size and generally poor preservation. The two most significant clams present are *Glycymeris* sp and *Linearia multicostata* (Gabb). Other forms present are *Trigonia, Astarte*(?), *Pentacrinus*, an Echinoderm plate, nuculid clams, *Limopsis,* bryozoa, corals(?), and other unidentifiable trash.

"As far as I know, *Glycymeris* is unknown in California rocks older than Late Cretaceous, and it first becomes abundant in rocks of Turonian age. *Linearia multicostata* is known to occur at only one other spot—central Oregon—in strata of Cenomanian age. The total range of this species is unknown, but it seems a fairly safe guess that the rocks that yielded the...assemblage are of early Late Cretaceous age, probably Cenomanian or Turonian, and definitely not Lower Cretaceous...". (Jones, April 20, 1970, written communication).

Locality B

Sample No.: SLO 3 (Stanford Univ. No. PL-3594)
Location: Roadcut west side Santa Lucia Road, 9,600 feet S. and 12,600 feet E. of NW corner Atascadero quadrangle.
Map Unit: "Paradise Valley sequence" unit 1, Atascadero Formation.
Collected by: E.W. Hart
Identified by: W.R. Evitt, Stanford University.
Description: "The sample is very sparsely fossiliferous. Several of the spores and gymnosperm pollen observed are of types that range from Late Jurassic to Paleocene. Two types of angiosperm pollen and one type of dinoflagellate, each represented by but a few specimens in the slides prepared, are the basis for saying probably Upper Cretaceous. Where within the U. Cret. it is not possible to say on the basis of the material available..." (Evitt, April 28, 1968, written communication). Another sample from this locality was reported to be barren of identifiable palynomorphs.

Locality G

Sample No.: SLO 207 (USGS No. M5361).
Location: 2,650 feet N. and 2,800 feet E. of SW cor. sec. 11, T. 29 S., R. 12 E., Atascadero quadrangle.
Map Unit: Atascadero Formation
Collected by: E.W. Hart
Identified by: D.L. Jones, U.S. Geological Survey, Menlo Park, Calif.
Description: "The only diagnostic fossil in this collection is *Glycymeris veatchii* (Gabb) var. *anae* Smith, which occurs as giant specimens. Similar forms are known from strata of very late (Campanian or younger) Cretaceous age in southern California". (Jones, April 23, 1970, written communication).